

## TITLE OF THE INVENTION

DEFLECTOR, METHOD OF MANUFACTURING DEFLECTOR, AND  
CHARGED PARTICLE BEAM EXPOSURE APPARATUS

## 5 FIELD OF THE INVENTION

The present invention relates to a charged particle beam exposure apparatus which exposes the pattern of a semiconductor integrated circuit or the like onto a wafer and, more particularly, to a  
10 deflector in a charged particle beam exposure apparatus which exposes a pattern by using a plurality of charged particle beams and a method of manufacturing the deflector.

## 15 BACKGROUND OF THE INVENTION

Along with the recent size reduction of semiconductor devices, various kinds of lithography means for 100 nm or less have been proposed. There are also requirements for high resolution, accurate  
20 lithography pattern overlay, and high throughput. Electron beam exposure apparatuses inherently ensure a high resolution and also have satisfactory dimension controllability as compared to other exposure means. Since the electron beam exposure apparatuses can  
25 electrically generate an exposure pattern and directly expose a wafer, they are expected as maskless exposure means.

In the electron beam exposure apparatuses, however, the exposure area per shot is small, and the throughput is low. For these reasons, they are not widely used for mass production of semiconductor devices. To solve these problems, a multi-electron beam exposure apparatus which exposes a wafer by using a plurality of electron beams simultaneously has been proposed.

Such a multi-electron beam exposure apparatus comprises a blanking aperture array device which switches a plurality of electron beams between an independent deflection mode and another mode, and an electron beam shielding section which shields the wafer from the electron beams deflected by the blanking aperture array device. With these units, whether the wafer is to be irradiated with each of the plurality of electron beams is accurately controlled. The blanking aperture array device has a substrate such as a semiconductor substrate having a plurality of openings (also called through holes), deflection electrodes formed in the openings, and an insulating layer which insulates the substrate from the deflection electrodes. Whether an electron beam that passes through an opening is to be deflected is controlled by ON/OFF-controlling voltage application to the deflection electrode.

In the conventional blanking aperture array device manufacturing process, openings each having a

high aspect ratio are formed in a substrate. A deflection electrode is formed in each of the openings by plating. Since the deflection electrode is formed by plating in the opening having a high aspect ratio, a material whose plating growth rate is low cannot be selected as the material of the deflection electrode. In addition, if the deflection electrode is oxidized, it becomes difficult to appropriately deflect an electron beam and control its position. To prevent this, a material that is hard to oxidize must be selected as the material of the deflection electrode. It is difficult to select the deflection electrode material that meets the above requirements.

In the conventional structure of the blanking aperture array device, the substrate or insulating layer is partially exposed to the inner wall of each opening through which an electron beam passes. For this reason, the oxide film of the substrate or the insulating layer, which is exposed to the inner wall of the opening, is charged up and affects the electron beam that passes through the opening. Accordingly, the electron beam cannot be appropriately deflected or position-controlled. Hence, it is difficult to accurately expose the wafer.

In the conventional blanking aperture array device manufacturing process, openings are formed in a substrate, and an insulating layer is formed on the

inner wall of each opening. At a position adjacent to the insulating layer, a deflection electrode is formed by plating using a conductive layer formed on the surface of the substrate as an electrode. The

5 deflection electrode has residual stress and therefore poor adhesion to the insulating layer. For this reason, the deflection electrode readily peels off from the insulating layer.

Under these circumstances, a deflector, a method  
10 of manufacturing the same, and a charged particle beam exposure apparatus, which can solve the above problems, are demanded.

#### SUMMARY OF THE INVENTION

15 According to one aspect of the present invention, there is provided a deflector which deflects a charged particle beam, comprising: a substrate having an opening through which the charged particle beam should pass; and a deflection electrode which is arranged in  
20 the opening to deflect the charged particle beam and has a first conductive member and second conductive member which are formed by plating, wherein the second conductive member is formed on a surface of the first conductive member and is essentially made of a material  
25 that is more difficult to oxidize than the first conductive member.

According to another aspect of the present

invention, there is provided a deflector which deflects a charged particle beam, comprising: a substrate having an opening through which the charged particle beam should pass; a first deflection electrode and second  
5 deflection electrode which oppose each other in the opening to deflect the charged particle beam; and a first conductive layer and second conductive layer which oppose each other in the opening in a direction substantially perpendicular to a direction from the  
10 first deflection electrode to the second deflection electrode and are made of a material having a higher conductivity than the substrate.

Furthermore, according to another aspect of the present invention, there is provided a deflector which  
15 deflects a charged particle beam, comprising: a substrate having a through hole through which the charged particle beam should pass and two groove portions respectively formed on two opposing side surfaces inside the through hole; and two deflection  
20 electrodes which are at least partially buried in the two groove portions, wherein each of the groove portions has a shape to lock the buried portion of the deflection electrode in the groove portion to prevent the deflection electrode from separating from the  
25 substrate.

According to another aspect of the present invention, there is provided a method of manufacturing

the deflector.

According to still another aspect of the present invention, there is provided a charged particle beam exposure apparatus using the deflector.

5           Other features and advantages of the present invention will be apparent from the following description taken in conjunction with the accompanying drawings, in which like reference characters designate the same or similar parts throughout the figures  
10   thereof.

#### BRIEF DESCRIPTION OF THE DRAWINGS

The accompanying drawings, which are incorporated in and constitute a part of the specification,  
15   illustrate embodiments of the invention and, together with the description, serve to explain the principles of the invention.

Fig. 1 is a view showing the arrangement of an electron beam exposure apparatus 100 according to an  
20   embodiment;

Fig. 2 is a view showing the structure of a blanking aperture array device 26;

Fig. 3 is a view showing the structure of an aperture portion 160;

25           Figs. 4A and 4B are views showing an example of the detailed structure of the blanking aperture array device 26 according to the first embodiment;

Fig. 5 is a view showing another example of the detailed structure of the blanking aperture array device 26 according to the first embodiment;

5 Figs. 6A to 6O are views showing a method of manufacturing the blanking aperture array device 26 according to the first embodiment;

Fig. 7 is a view showing an example of the detailed structure of a blanking aperture array device 26 according to the second embodiment;

10 Fig. 8 is a view showing another example of the detailed structure of the blanking aperture array device 26 according to the second embodiment;

Figs. 9A to 9P are views showing a method of manufacturing the blanking aperture array device 26 according to the second embodiment;

Fig. 10 is a view showing the detailed structure of a blanking aperture array device 26 according to the third embodiment;

20 Figs. 11A to 11N are views showing a method of manufacturing the blanking aperture array device 26 according to the third embodiment;

Fig. 12 is a view showing the detailed structure of a blanking aperture array device 26 according to the fourth embodiment; and

25 Figs. 13A to 13N are views showing a method of manufacturing the blanking aperture array device 26 according to the fourth embodiment.

## DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Preferred embodiments of the present invention will now be described in detail in accordance with the  
5 accompanying drawings.

Although the present invention will be described below on the basis of the embodiments of the invention, the embodiments to be described below do not limit the invention of appended claims. In addition, all  
10 combinations of characteristic features described in the embodiments are not always essential to the solving means of the invention.

## [First Embodiment]

Fig. 1 shows the arrangement of an electron beam  
15 exposure apparatus 100 according to the first embodiment. The electron beam exposure apparatus 100 is an example of the charged particle beam exposure apparatus of the present invention. The charged  
20 particle beam exposure apparatus of the present invention may be an ion beam exposure apparatus which exposes a wafer by an ion beam. The electron beam exposure apparatus 100 may generate a plurality of  
25 electron beams at a short interval and, for example, at such an interval that one chip region to be formed on a wafer is irradiated with all electron beams.

The electron beam exposure apparatus 100 comprises an exposure section 150 which executes

predetermined exposure processing for a wafer 44 by electron beams and a control section 140 which controls the operations of components included in the exposure section 150.

5           The exposure section 150 comprises an electron optical system and a stage system. The electron optical system includes an electron beam shaping means 110 for generating a plurality of electron beams in a housing 8 and forming the sectional shape of each  
10 electron beam into a desired shape, an irradiation switching means 112 for independently switching for each of the plurality of electron beams whether the wafer 44 should be irradiated with the electron beam, and a wafer projecting system 114 which adjusts the  
15 direction and size of the image of a pattern to be transferred to the wafer 44. The stage system has a wafer stage 46 on which the wafer 44 to which the pattern is to be exposed is placed and a wafer stage driving section 48 which drives the wafer stage 46.

20           The electron beam shaping means 110 has an electron beam generation section 10 which generates the plurality of electron beams, a first shaping member 14 and second shaping member 22 each of which has a plurality of opening portions that shape the sectional  
25 shapes of the electron beams, a first multi-axis electron lens 16 which independently focuses the plurality of electron beams and adjusts the focal

points of the electron beams, and a first shaping  
deflecting section 18 and second shaping deflecting  
section 20 each of which independently deflects the  
plurality of electron beams that have passed through  
5 the first shaping member 14. The electron beam  
generation section 10 is an example of the charged  
particle beam generation section of the present  
invention. The first shaping deflecting section 18 and  
second shaping deflecting section 20 are examples of  
10 the deflector of the present invention.

The electron beam generation section 10 has a  
plurality of electron guns 104 and a base 106 on which  
the electron guns 104 are formed. Each electron gun  
104 has a cathode 12 which generates thermoelectrons  
15 and a grid 102 which is formed around the cathode 12 to  
stabilize the thermoelectrons generated by the cathode  
12. In the electron beam generation section 10, the  
plurality of electron guns 104 are formed on the base  
106 at a predetermined interval so that an electron gun  
20 array is formed.

Each of the first shaping member 14 and second  
shaping member 22 preferably has a grounded metal film  
of platinum or the like on the surface that is  
irradiated with the electron beams. Each of the  
25 plurality of opening portions included in the first  
shaping member 14 and second shaping member 22 may have  
a sectional shape that extends along the electron beam

irradiation direction to efficiently pass the electron beam. The plurality of opening portions included in the first shaping member 14 and second shaping member 22 are preferably formed into a rectangular shape.

5           The irradiation switching means 112 has a second multi-axis electron lens 24 which independently focuses the plurality of electron beams and adjusts the focal points of the electron beams, a blanking aperture array device 26 which independently switches for each of the  
10 electron beams whether the wafer 44 should be irradiated with the electron beam by independently deflecting the electron beams, and an electron beam shielding member 28 which includes a plurality of opening portions through which the electron beams pass  
15 and shields the electron beams deflected by the blanking aperture array device 26. The blanking aperture array device 26 is an example of the deflector of the present invention.

          The blanking aperture array device 26 has a  
20 substrate having openings through which the electron beams should pass, and a plurality of deflection electrodes formed in the openings. Each of the plurality of opening portions included in the electron beam shielding member 28 may have a sectional shape  
25 that extends along the electron beam irradiation direction to efficiently pass the electron beam.

          The wafer projecting system 114 has a third

multi-axis electron lens 34 which independently focuses the plurality of electron beams and reduces the irradiation diameters of the electron beams, a fourth multi-axis electron lens 36 which independently focuses the plurality of electron beams and adjusts the focal points of the electron beams, a sub-deflecting section 38 serving as an independent deflecting portion section which independently deflects the plurality of electron beams to desired positions on the wafer 44, a coaxial lens 52 which has a first coil 40 and second coil 50 for focusing the electron beams and functions as an objective lens, and a main deflecting section 42 serving as a common deflecting section which deflects the plurality of electron beams by a desired amount to almost the same direction. The sub-deflecting section 38 is an example of the deflector of the present invention.

The main deflecting section 42 is preferably an electrostatic deflector capable of rapidly deflecting a plurality of electron beams by using an electric field and has opposing deflection electrodes. The main deflecting section 42 may have a cylindrical uniform 8-pole structure including four sets of opposing deflection electrodes or a structure including eight or more deflection electrodes. The blanking aperture array device 26 has one set of opposing deflection electrodes. The coaxial lens 52 is preferably arranged

to be closer to the wafer 44 than the fourth multi-axis electron lens 36.

The control section 140 comprises a collective control section 130 and individual control section 120.

5 The individual control section 120 has an electron beam control section 80, a multi-axis electron lens control section 82, a shaping deflection control section 84, a blanking aperture array control section 86, a coaxial lens control section 90, a sub-deflection control  
10 section 92, a main deflection control section 94, and a wafer stage control section 96. The collective control section 130 is, e.g., a workstation which collectively controls the control sections included in the individual control section 120.

15 The electron beam control section 80 controls the electron beam generation section 10. The multi-axis electron lens control section 82 controls a current to be supplied to the first multi-axis electron lens 16, second multi-axis electron lens 24, third multi-axis  
20 electron lens 34, and fourth multi-axis electron lens 36. The shaping deflection control section 84 controls the first shaping deflecting section 18 and second shaping deflecting section 20. The blanking aperture array control section 86 controls a voltage to be  
25 applied to the deflection electrodes included in the blanking aperture array device 26. The coaxial lens control section 90 controls a current to be supplied to

the first coil 40 and second coil 50 which are included in the coaxial lens 52. The main deflection control section 94 controls a voltage to be applied to the deflection electrodes included in the main deflecting section 42. The wafer stage control section 96 controls the wafer stage driving section 48 to move the wafer stage 46 to a predetermined position.

The operation of the electron beam exposure apparatus 100 will be described. First, the electron beam generation section 10 generates a plurality of electron beams. The first shaping member 14 is irradiated with the electron beams generated by the electron beam generation section 10 so that the electron beams are shaped. The plurality of electron beams that have passed through the first shaping member 14 have rectangular shapes corresponding to the shapes of the opening portions included in the first shaping member 14.

The first multi-axis electron lens 16 independently focuses the plurality of electron beams having the rectangular shapes and independently adjusts the focal point of each electron beam with respect to the second shaping member 22. The first shaping deflecting section 18 independently deflects each of the plurality of electron beams having the rectangular shapes to a desired position of the second shaping member. The second shaping deflecting section 20

independently deflects the plurality of electron beams, deflected by the first shaping deflecting section 18, almost perpendicularly to the second shaping member 22. As a result, each electron beam is adjusted such that  
5 it almost perpendicularly irradiates a desired position of the second shaping member 22. The second shaping member 22 including a plurality of opening portions each having a rectangular shape further shapes the plurality of electron beams each having a rectangular  
10 sectional shape and irradiating a corresponding opening portion, thereby forming electron beams each of which has a desired rectangular sectional shape and should irradiate the wafer 44.

The second multi-axis electron lens 24  
15 independently focuses the plurality of electron beams and adjusts the focal points of the electron beams with respect to the blanking aperture array device 26. The electron beams having focal points adjusted by the second multi-axis electron lens 24 pass through the  
20 plurality of opening portions included in the blanking aperture array device 26.

The blanking aperture array control section 86 controls whether a voltage is to be applied to the deflection electrode formed in each opening of the  
25 blanking aperture array device 26. On the basis of whether a voltage is to be applied to the deflection electrode, the blanking aperture array device 26

ON/OFF-controls electron beam irradiation of the wafer 44. When a voltage is applied to the deflection electrode, the electron beam that has passed through the opening of the blanking aperture array device 26 is deflected. Hence, the electron beam cannot pass through the opening portion included in the electron beam shielding member 28 so that the wafer 44 is not irradiated with the electron beam. When no voltage is applied to the deflection electrode, the electron beam that has passed through the opening of the blanking aperture array device 26 is not deflected. Hence, the electron beam can pass through the opening portion included in the electron beam shielding member 28 so that the wafer 44 is irradiated with the electron beam.

The third multi-axis electron lens 34 reduces the diameter of each electron beam which is not deflected by the blanking aperture array device 26 and passes the electron beam through an opening portion included in the electron beam shielding member 28. The fourth multi-axis electron lens 36 independently focuses the plurality of electron beams and adjusts the focal points of the electron beams with respect to the sub-deflecting section 38. The electron beams having the adjusted focal points become incident on the deflectors included in the sub-deflecting section 38.

The sub-deflection control section 92 independently controls the plurality of deflectors

included in the sub-deflecting section 38. The sub-deflecting section 38 independently deflects the plurality of electron beams incident on the plurality of deflectors to desired exposure positions of the wafer 44. The focal points of the plurality of electron beams that have passed through the sub-deflecting section 38 are adjusted with respect to the wafer 44 by the coaxial lens 52 having the first coil 40 and second coil 50 so that the wafer 44 is irradiated with the electron beams.

During exposure processing, the wafer stage control section 96 controls the wafer stage driving section 48 to move the wafer stage 46 to a predetermined direction. On the basis of exposure pattern data, the blanking aperture array control section 86 defines an opening through which an electron beam should pass and executes power control for the deflection electrode formed in each opening. As the wafer 44 moves, the opening through which the electron beam should pass is appropriately changed. In addition, the electron beam is deflected by the main deflecting section 42 and sub-deflecting section 38. With this operation, a desired circuit pattern can be exposed to the wafer 44.

In the first to fourth embodiments below, the structure and manufacturing method of the blanking aperture array device 26 will be described. The same

structure and manufacturing method can also be applied to the deflectors of the first shaping deflecting section 18, second shaping deflecting section 20, and sub-deflecting section 38.

5           Fig. 2 shows the structure of the blanking aperture array device 26. The blanking aperture array device 26 has an aperture portion 160 having a plurality of openings through which electron beams pass, and the deflection electrode pad 162 and ground  
10 electrode pad 164, which serve as connection portions to the blanking aperture array control section 86 shown in Fig. 1. The aperture portion 160 is preferably located at the central portion of the blanking aperture array device 26. The deflection electrode pad 162 and  
15 ground electrode pad 164 supply an electric signal supplied from the blanking aperture array control section 86 through a probe card and pogo-pin array to the deflection electrodes formed in the openings of the aperture portion 160.

20           Fig. 3 shows the structure of the aperture portion 160. An X-axis direction is defined in the lateral direction of the aperture portion 160. A Y-axis direction is defined in the vertical direction. The X-axis indicates the direction in which the wafer  
25 stage 46 moves the wafer 44 stepwise during exposure processing. The Y-axis indicates the direction in which the wafer stage 46 moves the wafer 44

continuously during exposure processing. More specifically, the Y-axis indicates the scanning/exposure direction of the wafer 44 with respect to the wafer stage 46. The X-axis indicates the direction in which the wafer 44 is moved stepwise to exposure unexposed regions of the wafer 44 after the end of scanning/exposure.

The aperture portion 160 has openings 200 through which the plurality of electron beams should pass. The plurality of openings 200 are laid out to expose the entire scanning region. For example, the plurality of openings 200 are laid out to cover the whole region between a plurality of openings 200a and 200b which are located at two ends in the X-axis direction. The openings 200 close in the X-axis direction are preferably laid out at a predetermined interval. The interval between the plurality of openings 200 is preferably defined to be equal to or smaller than the maximum deflection amount of electron beam deflection by the main deflecting section 42.

Figs. 4A and 4B show an example of the detailed structure of the blanking aperture array device 26 according to the first embodiment. Fig. 4B is a plan view. Fig. 4A is a sectional view taken along a line A - A'. The blanking aperture array device 26 comprises a substrate 202 having the openings 200 through which electron beams should pass, deflection

electrodes 206a and 206b that oppose each other in each opening 200 to deflect an electron beam, insulating layers 208a and 208b arranged between the substrate 202 and the deflection electrode 206a and between the  
5 substrate 202 and the deflection electrode 206b, respectively, an insulating layer 224 formed on the upper surface of the substrate 202, an interconnection layer 226 formed on the upper surface of the insulating layer 224, an insulating layer 228 formed on the upper  
10 surface of the interconnection layer 226, and a conductive film 230 formed on the upper surface of the insulating layer 228.

The insulating layers 208a and 208b electrically insulate the deflection electrodes 206a and 206b from  
15 the substrate 202. The insulating layer 224 electrically insulates the substrate 202 from the interconnection layer 226. The insulating layer 228 electrically insulates the interconnection layer 226 from the conductive film 230. The conductive film 230  
20 is electrically connected to the ground electrode pad 164 shown in Fig. 2 and thus grounded. The conductive film 230 functions as an anti-charge-up metal layer for the insulating layer 228. The deflection electrodes 206a and 206b are electrically connected to the  
25 deflection electrode pad 162 shown in Fig. 2 through the interconnection layer 226.

The deflection electrode 206a has a conductive

member 204a and a conductive member 205a formed on the surface of the conductive member 204a. The deflection electrode 206b has a conductive member 204b and a conductive member 205b formed on the surface of the conductive member 204b. The conductive members 205a and 205b are preferably made of a material that is more difficult to oxidize than the conductive members 204a and 204b. The conductive members 204a and 204b are preferably made of a material having a higher plating growth rate than the conductive members 205a and 205b. The conductive members 204a and 204b are preferably made of a material whose residual stress after plating growth is smaller than the conductive members 205a and 205b. The conductive members 204a and 204b and conductive members 205a and 205b are preferably made of materials having high ionization tendency. For example, the conductive members 204a and 204b are made of Cu while the conductive members 205a and 205b are made of Au. The conductive members 204a and 204b may be made of a copper alloy containing a trace quantity of Be in Cu. The conductive members 205a and 205b may be made of a gold alloy containing a trace quantity of Ag or Pt in Au.

The substrate 202 is, e.g., a silicon substrate. The insulating layers 208a and 208b are oxide films formed by thermally oxidizing the substrate 202 and, for example, silicon oxide films formed by thermally

oxidizing a silicon substrate.

According to the blanking aperture array device 26 of this embodiment, the conductive members 205a and 205b which are difficult to oxidize are formed as the peripheral portions of the deflection electrodes 206a and 206b. The deflection electrodes 206a and 206b are bonded to the insulating layers 208a and 208b through the conductive members 204a and 204b with small residual stress. For this reason, degradation of the deflection electrodes 206a and 206b due to oxidization can be prevented while maintaining the bonding strength. Hence, the blanking aperture array device 26 with a long service life can be provided.

Fig. 5 shows another example of the detailed structure of the blanking aperture array device 26 according to the first embodiment. The structure of the blanking aperture array device 26 shown in Fig. 5 is the same as in Fig. 4 except the following description. The deflection electrode 206a also has a conductive member 205c formed on the surface of the conductive member 205a. The deflection electrode 206b also has a conductive member 205d formed on the surface of the conductive member 205b. The conductive members 205c and 205d are preferably made of a material that is more difficult to oxidize than the conductive members 205a and 205b. The conductive members 205c and 205d are preferably made of a material having a lower

plating growth rate than the conductive members 205a and 205b. The conductive members 205c and 205d are preferably made of a material whose residual stress after plating growth is larger than the conductive  
5 members 205a and 205b.

Figs. 6A to 6O show a method of manufacturing the blanking aperture array device 26. First, as shown in Fig. 6A, the substrate 202 is prepared. Silicon nitride films 210a and 210b are formed on the upper and  
10 lower surfaces of the substrate 202, respectively. The silicon nitride films 210a and 210b may be formed either simultaneously or separately. The substrate 202 is a silicon wafer having, e.g., a diameter of 6 inches and a thickness of 200  $\mu\text{m}$ . Each of the silicon  
15 nitride films 210a and 210b has a thickness of, e.g., 1  $\mu\text{m}$ .

Next, as shown in Fig. 6B, a resist 212 is applied to the upper surface of the silicon nitride film 210a. Exposure and development are performed, and  
20 the resist 212 is removed from regions where the conductive members 204a and 204b are to be formed. The silicon nitride film 210a in the regions where the conductive members 204a and 204b are to be formed is removed by etching such as reactive ion etching (RIE)  
25 using the resist 212 as an etching mask.

As shown in Fig. 6C, the substrate 202 at the portions where the conductive members 204a and 204b are

to be formed is removed by etching such as inductively coupled plasma etching (ICP-RIE) using both or one of the resist 212 and silicon nitride film 210a as an etching mask, thereby forming a plurality of openings 214a and 214b. The silicon nitride film 210b serves as an etching stopper layer in etching the substrate 202.

As shown in Fig. 6D, the resist 212 is removed. After that, the insulating layers 208a and 208b are formed on the inner walls of the plurality of openings 214a and 214b formed in the substrate 202. The insulating layers 208a and 208b are formed by, e.g., thermally oxidizing the inner walls of the plurality of openings 214a and 214b. More specifically, of the inner walls of the plurality of openings 214a and 214b formed in the substrate 202 as a silicon substrate, silicon exposed surfaces except portions covered with the silicon nitride films 210a and 210b are selectively thermally oxidized, thereby forming the insulating layers 208a and 208b as silicon oxide films.

As shown in Fig. 6E, a conductive film 216 is formed on the silicon nitride film 210b. An insulating layer 218 is formed on the conductive film 216. More specifically, a 50-nm thick Cr film, a 200-nm thick Au film, and a 50-nm thick Cr film are formed in this order by e.g. EB deposition to form the conductive film 216 having a multilayered structure of Cr/Au/Cr. When the multilayered structure of Cr/Au/Cr is formed as the

conductive film 216, the adhesion between the silicon nitride film 210b and the conductive film 216 can be increased. If the adhesion between the silicon nitride film 210b and the conductive film 216 has no problem, the conductive film 216 may be, e.g., an Au film having a single-layered structure. The insulating layer 218 made of a silicon oxide film is formed on the conductive film 216 by e.g. plasma chemical vapor deposition (CVD). The silicon nitride film 210b formed in Fig. 6A is used to electrically insulate the substrate 202 from the conductive film 216.

As shown in Fig. 6F, the silicon nitride film 210a and the portions of the silicon nitride film 210b, which are exposed to the plurality of openings 214a and 214b, are selectively removed by, e.g., RIE. At this time, without removing the insulating layers 208a and 208b formed on the sidewalls of the openings 214a and 214b, the silicon nitride film 210b is etched until the conductive film 216 is exposed to the openings 214a and 214b. In addition, the Cr film of the conductive film 216 is etched until the Au film is exposed. In another example, without removing the insulating layers 208a and 208b formed on the sidewalls of the openings 214a and 214b, the silicon nitride film 210a and the portions of the silicon nitride film 210b, which are exposed to the plurality of openings 214a and 214b, may be removed by wet etching using hot phosphoric acid.

After that, the Cr film of the conductive film 216 may be removed by etching in the same way.

As shown in Fig. 6G, the conductive members 204a and 204b are formed by selectively executing electrolytic plating in the plurality of openings 214a and 214b by using the Au film of the conductive film 216 as a plating electrode (seed layer). The conductive members 204a and 204b are made of, e.g., Cu. After the conductive members 204a and 204b are formed, the conductive members 204a and 204b formed outside the openings 214a and 214b are removed by, e.g., chemical mechanical polishing (CMP). In another example, after Cr films are formed on the surfaces of the insulating layers 208a and 208b exposed to the plurality of openings 214a and 214b by sputtering, the conductive members 204a and 204b may be formed inside the Cr films in the plurality of openings 214a and 214b. With this structure, the adhesion between the conductive members 204a and 204b and the insulating layers 208a and 208b can be increased.

As shown in Fig. 6H, an insulating layer 224 and interconnection layer 226 are formed on the substrate 202. More specifically, the insulating layer 224 as a silicon oxide film having a thickness of about 1  $\mu\text{m}$  is formed by e.g. plasma CVD. A resist is applied to the surface of the insulating layer 224. Exposure and development are performed, and the resist above the

conductive members 204a and 204b is removed. The insulating layer 224 is removed by etching such as RIE using the resist as an etching mask. After the resist is removed, a Cr film and Au film are deposited on the surface of the insulating layer 224 in this order by sputtering, thereby forming the interconnection layer 226 electrically connected to the conductive members 204a and 204b.

As shown in Fig. 6I, an interconnection pattern is formed on the interconnection layer 226. More specifically, a resist is applied to the surface of the interconnection layer 226. Exposure and development are performed, and the resist is removed from a region where no interconnection is to be formed. The interconnection layer 226 is removed by etching such as RIE using the resist as an etching mask, thereby forming the interconnection pattern. Then, the resist is removed.

As shown in Fig. 6J, an insulating layer 228 and conductive film 230 are formed on the insulating layer 224 and interconnection layer 226. More specifically, the insulating layer 228 as a silicon oxide film having a thickness of about 1  $\mu\text{m}$  is formed by e.g. plasma CVD. A Cr film and Au film are deposited on the surface of the insulating layer 228 in this order by sputtering to form the conductive film 230.

As shown in Fig. 6K, a resist 232 is applied to

the surface of the conductive film 230. Exposure and development are performed, and the resist 232 is removed from a region where the opening 200 through which an electron beam should pass is to be formed.

- 5 Using the resist 232 as an etching mask, the conductive film 230 is removed by etching such as ion milling, and the insulating layers 224 and 228 are removed by etching such as RIE.

- As shown in Fig. 6L, the substrate 202 is removed  
10 by etching such as ICP-RIE using the resist 232 as an etching mask.

- As shown in Fig. 6M, the portions of the insulating layers 208a and 208b, which are exposed to the opening 200, the insulating layer 218, and the  
15 conductive film 216 are removed by etching. More specifically, while leaving the resist 232, the insulating layers 208a and 208b as silicon oxide films on the sidewall of the opening 200 are removed by wet etching using a solution mixture of, e.g., HF and  $\text{NH}_4\text{F}$ .  
20 Simultaneously, the insulating layer 218 is also removed by wet etching. The Cr film of the conductive film 216 is removed by wet etching using a solution mixture of, e.g., cerium ammonium nitrate (IV), perchloric acid, and water. The Au film of the  
25 conductive film 216 is removed by wet etching using a solution mixture of, e.g., potassium iodide, iodine, and water.

As shown in Fig. 6N, after the resist 232 is removed, the silicon nitride film 210b is removed by etching. More specifically, the silicon nitride film 210b is removed by wet etching using, e.g., hot  
5 phosphoric acid to make the opening 200 through.

As shown in Fig. 6O, the conductive members 205a and 205b are formed on the surfaces of the conductive members 204a and 204b. For example, power is supplied from the interconnection layer 226 to the conductive  
10 members 204a and 204b by using the interconnection layer 226 as a plating electrode so that the conductive members 205a and 205b are formed on the surfaces of the conductive members 204a and 204b by electrolytic plating. More specifically, the conductive members  
15 205a and 205b are made of Au. In another example, the surfaces of the conductive members 204a and 204b may be subjected to activation processing, and the conductive members 205a and 205b may be formed on the surfaces of the conductive members 204a and 204b by electroless  
20 plating such as chemical plating or displacement plating. More specifically, the surfaces of the conductive members 204a and 204b made of Cu are subjected to activation processing by acid treatment using an acid except hydrofluoric acid and degreasing  
25 cleaning, thereby activating (ionizing) only the surfaces of the conductive members 204a and 204b. Then, using a plating solution containing Au, Au is

immersion plating on the surfaces of the conductive members 204a and 204b having high ionization tendency, thereby forming the conductive members 205a and 205b.

If the conductive members 205c and 205d are also  
5 to be formed, as shown in Fig. 5, the same procedures as in formation of the conductive members 205a and 205b are used.

In this embodiment, the lower surface of the substrate 202 is exposed. However, a conductive film  
10 may be formed on the lower surface of the substrate 202 to prevent the substrate 202 from being charged up. In the above way, the blanking aperture array device 26 is completed by the manufacturing method shown in Figs. 6A to 6O.

15 According to the blanking aperture array device 26 of this embodiment, even when the deflection electrodes 206a and 206b are formed in the openings 214a and 214b having a high aspect ratio, the time required for manufacturing the blanking aperture array  
20 device 26 can be shortened because most portions of the deflection electrodes 206a and 206b are formed by the conductive members 204a and 204b having a high plating growth rate. In addition, the peripheral portions of the deflection electrodes 206a and 206b are formed from  
25 the conductive members 205a and 205b which are difficult to oxidize. For this reason, degradation of the deflection electrodes 206a and 206b due to

oxidization can be prevented. Hence, the reliability of electron beam deflection by the blanking aperture array device 26 can be increased. In addition, the service life of the blanking aperture array device 26  
5 can be prolonged.

[Second Embodiment]

The second embodiment will be described next. The arrangement of an electron beam exposure apparatus 100, the structure of a blanking aperture array device  
10 26, and the structure of an aperture portion 160 are the same as in the first embodiment (Figs. 1 to 3).

Fig. 7 shows the detailed structure of the blanking aperture array device 26 according to the second embodiment. Fig. 7 is a plan view of the  
15 blanking aperture array device 26 viewed from the lower surface.

The blanking aperture array device 26 comprises a substrate 1202 having an opening 200 through which an electron beam should pass, deflection electrodes 1204a and 1204b that oppose each other in the opening 200 to  
20 deflect an electron beam, conductive layers 1206a and 1206b which are formed almost perpendicularly to the direction from the deflection electrode 1204a to the deflection electrode 1204b while opposing each other in  
25 the opening 200, and insulating layers 1208a and 1208b formed between the substrate 1202 and the deflection electrode 1204a and between the substrate 1202 and the

deflection electrode 1204b, respectively.

The conductive layers 1206a and 1206b are electrically connected to a ground electrode pad 164 shown in Fig. 2 and thus grounded. The conductive  
5 layers 1206a and 1206b may be connected to the ground electrode pad 164 either directly or via the substrate 1202.

The conductive layers 1206a and 1206b are preferably made of a material having a high  
10 conductivity than the substrate 1202. The conductive layers 1206a and 1206b are preferably formed by metal plating. The substrate 1202 is, e.g., a silicon substrate. The conductive layers 1206a and 1206b are made of, e.g., a material containing Au or Cu as a  
15 principal component.

The insulating layers 1208a and 1208b are oxide films formed by thermally oxidizing the substrate 1202 and, for example, silicon oxide films formed by thermally oxidizing a silicon substrate. In the  
20 direction almost perpendicular to the direction from the deflection electrode 1204a to the deflection electrode 1204b and the electron beam irradiation direction, the length of each of the insulating layers 1208a and 1208b is preferably smaller than the length  
25 of each of the deflection electrodes 1204a and 1204b. That is, the insulating layers 1208a and 1208b are shielded from the path of an electron beam by the

deflection electrodes 1204a and 1204b. Hence, the insulating layers 1208a and 1208b can be prevented from being charged up.

The interval between the deflection electrode 1204a and the deflection electrode 1204b is preferably smaller than the interval between the conductive layer 1206a and the conductive layer 1206b. The conductive layers 1206a and 1206b may be thinner than the deflection electrodes 1204a and 1204b. More specifically, the deflection electrodes 1204a and 1204b are formed at an interval of several ten  $\mu\text{m}$ . When the interval between the deflection electrode 1204a and the deflection electrode 1204b is small, the electron beam can be accurately deflected. In addition, the voltage applied to the deflection electrodes 1204a and 1204b can be made low.

According to the blanking aperture array device 26 of this embodiment, since the conductive layers 1206a and 1206b are formed on the inner wall of the opening 200, native oxidation of the substrate 1202 can be prevented. Since any native oxide film such as a silicon oxide film that affects the electron beam upon being charged up is not formed on the inner surface of the opening 200, the electron beam can be accurately deflected.

Fig. 8 shows a modification of the detailed structure of the blanking aperture array device 26

according to the second embodiment. Fig. 8 is a plan view of the blanking aperture array device 26 viewed from the lower surface. The same reference numerals as in the blanking aperture array device 26 (Fig. 7)

5 according to the second embodiment denote the same constituent elements in Fig. 8, and a description thereof will be simplified or omitted. Different portions will be described in detail.

The conductive layers 1206a and 1206b are formed  
10 from a position adjacent to the insulating layer 1208a to a position adjacent to the insulating layer 1208b. More specifically, the conductive layers 1206a and 1206b are formed on the inner wall of the opening 200 from a surface on which the deflection electrode 1204a  
15 is formed to a surface on which the deflection electrode 1204b is formed. The conductive layers 1206a and 1206b are also formed from the upper end to the lower end of the opening 200 not to make the substrate 1202 expose into the opening 200. In this case, the  
20 conductive layers 1206a and 1206b and the deflection electrodes 1204a and 1204b are formed not to come into contact with each other.

More specifically, in each of the deflection electrodes 1204a and 1204b, the surface that opposes  
25 the other deflection electrode, i.e., the area of the surface that opposes the electron beam is preferably larger than the area of the surface that opposes the

substrate 202, i.e., the area of the surface that is in contact with a corresponding one of the insulating layers 1208a and 1208b. For example, each of the deflection electrodes 1204a and 1204b has a trapezoidal columnar shape that is tapered along a direction from the center of the opening 200, i.e., the position at which the electron beam should pass, to the inner wall of the opening 200. In addition, in the direction almost perpendicular to the direction from the deflection electrode 1204a to the deflection electrode 1204b, the width of the surface of each of the deflection electrodes 1204a and 1204b, which opposes the substrate 1202, may be equal to or more than the width of each of the insulating layers 1208a and 1208b.

According to the blanking aperture array device 26 of this embodiment, the conductive layers 1206a and 1206b are formed to cover the inner wall of the opening 200. For this reason, the influence of the charged-up substrate 1202 on the electron beam can be greatly reduced. Accordingly, the electron beam can be accurately deflected.

Figs. 9A to 9P show a method of manufacturing the blanking aperture array device 26 according to the second embodiment shown in Fig. 7 or its modification shown in Fig. 8. Figs. 9A to 9P are sectional views of the blanking aperture array device 26 taken along a line A - A' in Fig. 7 or 8.

First, as shown in Fig. 9A, the substrate 1202 is prepared. Silicon nitride films 1210a and 1210b are formed on the upper and lower surfaces of the substrate 1202, respectively. The silicon nitride films 1210a  
5 and 1210b may be formed either simultaneously or separately. The substrate 1202 is a silicon wafer having, e.g., a diameter of 6 inches and a thickness of 200  $\mu\text{m}$ . Each of the silicon nitride films 1210a and 1210b has a thickness of, e.g., 1  $\mu\text{m}$ .

10 Next, as shown in Fig. 9B, a resist 1212 is applied to the upper surface of the silicon nitride film 1210a. Exposure and development are performed, and the resist 1212 is removed from regions where the deflection electrodes 1204a and 1204b are to be formed.  
15 The silicon nitride film 1210a in the regions where the deflection electrodes 1204a and 1204b are to be formed is removed by etching such as reactive ion etching (RIE) using the resist 1212 as an etching mask.

As shown in Fig. 9C, the substrate 1202 at the  
20 portions where the deflection electrodes 1204a and 1204b are to be formed is removed by etching such as inductively coupled plasma etching (ICP-RIE) using both or one of the resist 1212 and silicon nitride film 1210a as an etching mask, thereby forming a plurality  
25 of openings 1214. The silicon nitride film 1210b serves as an etching stopper layer in etching the substrate 1202.

As shown in Fig. 9D, the resist 1212 is removed. After that, the insulating layers 1208a and 1208b are formed on the inner walls of the plurality of openings 1214 formed in the substrate 1202. The insulating  
5 layers 1208a and 1208b are formed by, e.g., thermally oxidizing the inner walls of the plurality of openings 1214. More specifically, of the inner walls of the plurality of openings 1214 formed in the substrate 1202 as a silicon substrate, silicon exposed surfaces except  
10 portions covered with the silicon nitride films 1210a and 1210b are selectively thermally oxidized, thereby forming the insulating layers 1208a and 1208b as silicon oxide films.

As shown in Fig. 9E, a conductive film 1216 is  
15 formed on the silicon nitride film 1210b. An insulating layer 1218 is formed on the conductive film 1216. More specifically, a 50-nm thick Cr film, a 200-nm thick Au film, and a 50-nm thick Cr film are formed in this order by e.g. EB deposition to form the  
20 conductive film 1216 having a multilayered structure of Cr/Au/Cr. When the multilayered structure of Cr/Au/Cr is formed as the conductive film 1216, the adhesion between the silicon nitride film 1210b and the conductive film 1216 can be increased. If the adhesion  
25 between the silicon nitride film 1210b and the conductive film 1216 has no problem, the conductive film 1216 may be, e.g., an Au film having a

single-layered structure. The insulating layer 1218 made of a silicon oxide film is formed on the conductive film 1216 by e.g. plasma chemical vapor deposition (CVD). The silicon nitride film 1210b formed in Fig. 9A is used to electrically insulate the substrate 1202 from the conductive film 1216.

As shown in Fig. 9F, the silicon nitride film 1210a and the portions of the silicon nitride film 1210b, which are exposed to the plurality of openings 1214, are selectively removed by, e.g., RIE. At this time, without removing the insulating layers 1208a and 1208b formed on the sidewalls of the plurality of openings 1214, the silicon nitride film 1210b is etched until the conductive film 1216 is exposed to the plurality of openings 1214. In addition, the Cr film of the conductive film 1216 is etched until the Au film is exposed. In another example, without removing the insulating layers 1208a and 1208b formed on the sidewalls of the plurality of openings 1214, the silicon nitride film 1210a and the portions of the silicon nitride film 1210b, which are exposed to the plurality of openings 1214, may be removed by wet etching using hot phosphoric acid. After that, the Cr film of the conductive film 1216 may be removed by etching in the same way.

As shown in Fig. 9G, the deflection electrodes 1204a and 1204b are formed by selectively executing

electrolytic plating in the plurality of openings 1214 by using the Au film of the conductive film 1216 as a plating electrode (seed layer) and filling the openings 1214 with a conductive material. The deflection electrodes 1204a and 1204b are made of, e.g., Cu or Au. After the deflection electrodes 1204a and 1204b are formed, the conductive material of the deflection electrodes 1204a and 1204b, which is formed outside the openings 1214, is removed by, e.g., chemical mechanical polishing (CMP). In another example, after Cr films are formed on the surfaces of the insulating layers 1208a and 1208b exposed to the plurality of openings 1214 by sputtering, the interiors of the Cr films of the plurality of openings 1214 may be filled with the conductive material to form the deflection electrodes 1204a and 1204b. With this structure, the adhesion between the deflection electrodes 1204a and 1204b and the insulating layers 1208a and 1208b can be increased.

As shown in Fig. 9H, a resist 1220 is applied to the upper surface of the substrate 1202. Exposure and development are performed, and the resist 1220 is removed from regions where the conductive layers 1206a and 1206b are to be formed. The substrate 1202 at portions where the conductive layers 1206a and 1206b are to be formed is selectively removed by etching such as RIE using the resist 1220 as an etching mask, thereby forming openings 1222. Portions of the silicon

nitride film 1210b, which are exposed to the openings 1222, are selectively removed by, e.g., RIE. In addition, the Cr film of the conductive film 1216 is etched until the Au film is exposed. In another  
5 example, the portions of the silicon nitride film 1210b, which are exposed to the openings 1222, and the Cr film of the conductive film 1216 may be removed by wet etching using hot phosphoric acid.

As shown in Fig. 9I, the conductive layers 1206a  
10 and 1206b are formed by selectively executing electrolytic plating in the openings 1222 by using the Au film of the conductive film 1216 as a plating electrode (seed layer) and filling the openings 1222 with a conductive material. The conductive layers  
15 1206a and 1206b are made of, e.g., Cu. After the conductive layers 1206a and 1206b are formed, the resist 1220 is removed, and an unnecessary conductive material is removed by, e.g., CMP. In another example, after Cr films are formed on the surfaces of the  
20 substrate 1202 exposed to the openings 1222 by sputtering, the interiors of the Cr films of the openings 1222 may be filled with the conductive material to form the conductive layers 1206a and 1206b. With this structure, the adhesion between the  
25 conductive layers 1206a and 1206b and the substrate 1202 can be increased.

As shown in Fig. 9J, an insulating layer 1224 and

interconnection layer 1226 are formed on the substrate 1202. More specifically, the insulating layer 1224 as a silicon oxide film having a thickness of about 1  $\mu\text{m}$  is formed by e.g. plasma CVD. A resist is applied to the surface of the insulating layer 1224. Exposure and development are performed, and the resist above the deflection electrodes 1204a and 1204b is removed. The insulating layer 1224 is removed by etching such as RIE using the resist as an etching mask. After the resist is removed, a Cr film and Au film are deposited on the surface of the insulating layer 1224 in this order by sputtering, thereby forming the interconnection layer 1226.

As shown in Fig. 9K, an interconnection pattern is formed on the interconnection layer 1226. More specifically, a resist is applied to the surface of the interconnection layer 1226. Exposure and development are performed, and the resist is removed from a region where no interconnection is to be formed. The interconnection layer 1226 is removed by etching such as RIE using the resist as an etching mask, thereby forming the interconnection pattern. Then, the resist is removed.

As shown in Fig. 9L, an insulating layer 1228 and conductive film 1230 are formed on the insulating layer 1224 and interconnection layer 1226. More specifically, the insulating layer 1228 as a silicon

oxide film having a thickness of about 1  $\mu\text{m}$  is formed by e.g. plasma CVD. A Cr film and Au film are deposited on the surface of the insulating layer 1228 in this order by sputtering to form the conductive film 1230. The conductive film 1230 is grounded and thus functions as an anti-charge-up metal layer for the insulating layer 1228.

As shown in Fig. 9M, a resist 1232 is applied to the surface of the conductive film 1230. Exposure and development are performed, and the resist 1232 is removed from a region where the opening 200 through which an electron beam should pass is to be formed. Using the resist 1232 as an etching mask, the conductive film 1230 is removed by etching such as ion milling, and the insulating layers 1224 and 1228 are removed by etching such as RIE.

As shown in Fig. 9N, the substrate 1202 is removed by etching such as ICP-RIE using the resist 1232 as an etching mask. At this time, the opening 200 having an I shape when viewed from the upper side is formed.

As shown in Fig. 9O, the portions of the insulating layers 1208a and 1208b, which are exposed to the opening 200, the insulating layer 1218, and the conductive film 1216 are removed by etching. More specifically, while leaving the resist 1232, the insulating layers 1208a and 1208b as silicon oxide

films on the sidewall of the opening 200 are removed by wet etching using a solution mixture of, e.g., HF and  $\text{NH}_4\text{F}$ . Simultaneously, the insulating layer 1218 is also removed by wet etching. The Cr film of the conductive film 1216 is removed by wet etching using a solution mixture of, e.g., cerium ammonium nitrate (IV), perchloric acid, and water. The Au film of the conductive film 1216 is removed by wet etching using a solution mixture of, e.g., potassium iodide, iodine, and water.

As shown in Fig. 9P, after the resist 1232 is removed, the silicon nitride film 1210b is removed by etching. More specifically, the silicon nitride film 1210b is removed by wet etching using, e.g., hot phosphoric acid to make the opening 200 through. In this embodiment, the lower surface of the substrate 1202 is exposed. However, a conductive film may be formed on the lower surface of the substrate 1202 to prevent the substrate 1202 from being charged up. In the above way, the blanking aperture array device 26 is completed by the manufacturing method shown in Figs. 9A to 9P.

According to the blanking aperture array devices 26 according to the second embodiment and its modification, since the conductive layers 1206a and 1206b are in contact with the substrate 1202, the conductive layers 1206a and 1206b can be grounded

through the substrate 1202. Hence, no interconnection need be formed to ground the conductive layers 1206a and 1206b, and the interconnection density can be reduced.

5 [Third Embodiment]

Fig. 10 shows the detailed structure of a blanking aperture array device 26 according to the third embodiment. Fig. 10 is a plan view of the blanking aperture array device 26 viewed from the lower  
10 surface. The same reference numerals as in the blanking aperture array devices 26 according to the second embodiment and its modification denote the same constituent elements in the third embodiment, and a description thereof will be simplified or omitted.  
15 Different portions will be described in detail.

The blanking aperture array device 26 further comprises insulating layers 1208c and 1208d formed between a substrate 1202 and a conductive layer 1206a and between the substrate 1202 and a conductive layer  
20 1206b. Insulating layers 1208a and 1208b and the insulating layers 1208c and 1208d can be made of the same material and have almost the same thickness.

Like the insulating layers 1208a and 1208b, the insulating layers 1208c and 1208d are oxide films  
25 formed by thermally oxidizing the substrate 1202 and, for example, silicon oxide films formed by thermally oxidizing a silicon substrate. In the direction from a

deflection electrode 1204a to a deflection electrode 1204b, the width of each of the insulating layers 1208c and 1208d is preferably smaller than the width of each of the conductive layers 1206a and 1206b. That is, the  
5 insulating layers 1208c and 1208d are shielded from the path of an electron beam by the conductive layers 1206a and 1206b. Hence, the insulating layers 1208c and 1208d can be prevented from being charged up.

Figs. 11A to 11N show a method of manufacturing  
10 the blanking aperture array device 26 according to the third embodiment. Figs. 11A to 11N are sectional views of the blanking aperture array device 26 taken along a line B - B' in Fig. 10.

First, as shown in Fig. 11A, the substrate 1202  
15 is prepared. Silicon nitride films 1210a and 1210b are formed on the upper and lower surfaces of the substrate 1202, respectively. The silicon nitride films 1210a and 1210b may be formed either simultaneously or separately. The substrate 1202 is a silicon wafer  
20 having, e.g., a diameter of 6 inches and a thickness of 200  $\mu\text{m}$ . Each of the silicon nitride films 1210a and 1210b has a thickness of, e.g., 1  $\mu\text{m}$ .

Next, as shown in Fig. 11B, a resist 1212 is applied to the upper surface of the silicon nitride  
25 film 1210a. Exposure and development are performed, and the resist 1212 is removed from regions where the deflection electrodes 1204a and 1204b and conductive

layers 1206a and 1206b are to be formed. The silicon nitride film 1210a in the regions where the deflection electrodes 1204a and 1204b and conductive layers 1206a and 1206b are to be formed is removed by etching such as RIE using the resist 1212 as an etching mask.

As shown in Fig. 11C, the substrate 1202 at the portions where the deflection electrodes 1204a and 1204b and conductive layers 1206a and 1206b are to be formed is removed by etching such as ICP-RIE using both or one of the resist 1212 and silicon nitride film 1210b as an etching mask, thereby forming a plurality of openings 1214 and 1222. The silicon nitride film 1210b serves as an etching stopper layer in etching the substrate 1202.

As shown in Fig. 11D, the resist 1212 is removed. After that, the insulating layers 1208a, 1208b, 1208c, and 1208d are formed on the inner walls of the plurality of openings 1214 and 1222 formed in the substrate 1202. The insulating layers 1208a, 1208b, 1208c, and 1208d are formed by, e.g., thermally oxidizing the inner walls of the plurality of openings 1214 and 1222. More specifically, of the inner walls of the plurality of openings 1214 and 1222 formed in the substrate 1202 as a silicon substrate, silicon exposed surfaces except portions covered with the silicon nitride films 1210a and 1210b are selectively thermally oxidized, thereby forming the insulating

layers 1208a, 1208b, 1208c, and 1208d as silicon oxide films.

As shown in Fig. 11E, a conductive film 1216 is formed on the silicon nitride film 1210b. An  
5 insulating layer 1218 is formed on the conductive film 1216. More specifically, a 50-nm thick Cr film, a 200-nm thick Au film, and a 50-nm thick Cr film are formed in this order by e.g. EB deposition to form the conductive film 1216 having a multilayered structure of  
10 Cr/Au/Cr. When the multilayered structure of Cr/Au/Cr is formed as the conductive film 1216, the adhesion between the silicon nitride film 1210b and the conductive film 1216 can be increased. If the adhesion between the silicon nitride film 1210b and the  
15 conductive film 1216 has no problem, the conductive film 1216 may be, e.g., an Au film having a single-layered structure. The insulating layer 1218 made of a silicon oxide film is formed on the conductive film 1216 by e.g. plasma CVD. The silicon  
20 nitride film 1210b formed in Fig. 11A is used to electrically insulate the substrate 1202 from the conductive film 1216.

As shown in Fig. 11F, the silicon nitride film 1210a and the portions of the silicon nitride film  
25 1210b, which are exposed to the plurality of openings 1214 and 1222, are selectively removed by, e.g., RIE. At this time, without removing the insulating layers

1208a, 1208b, 1208c, and 1208d formed on the sidewalls of the plurality of openings 1214 and 1222, the silicon nitride film 1210b is etched until the conductive film 1216 is exposed to the plurality of openings 1214 and 1222. In addition, the Cr film of the conductive film 1216 is etched until the Au film is exposed. In another example, without removing the insulating layers 1208a, 1208b, 1208c, and 1208d formed on the sidewalls of the plurality of openings 1214 and 1222, the silicon nitride film 1210a and the portions of the silicon nitride film 1210b, which are exposed to the plurality of openings 1214 and 1222, may be removed by wet etching using hot phosphoric acid. After that, the Cr film of the conductive film 1216 may be removed by etching in the same way.

As shown in Fig. 11G, the deflection electrodes 1204a and 1204b and conductive layers 1206a and 1206b are formed by selectively executing electrolytic plating in the plurality of openings 1214 and 1222 by using the Au film of the conductive film 1216 as a plating electrode (seed layer) and filling the openings 1214 and 1222 with a conductive material. The deflection electrodes 1204a and 1204b and conductive layers 1206a and 1206b are made of, e.g., Cu or Au. After the deflection electrodes 1204a and 1204b and conductive layers 1206a and 1206b are formed, an unnecessary conductive material is removed by, e.g.,

CMP. In another example, after Cr films are formed on the surfaces of the insulating layers 1208a, 1208b, 1208c, and 1208d exposed to the plurality of openings 1214 and 1222 by sputtering, the interiors of the Cr films of the plurality of openings 1214 and 1222 may be filled with the conductive material to form the deflection electrodes 1204a and 1204b and conductive layers 1206a and 1206b. With this structure, the adhesion between the deflection electrodes 1204a and 1204b and conductive layers 1206a and 1206b and the insulating layers 1208a, 1208b, 1208c, and 1208d can be increased.

As shown in Fig. 11H, an insulating layer 1224 and interconnection layer 1226 are formed on the substrate 1202. More specifically, the insulating layer 1224 as a silicon oxide film having a thickness of about 1  $\mu\text{m}$  is formed by e.g. plasma CVD. A resist is applied to the surface of the insulating layer 1224. Exposure and development are performed, and the resist above the deflection electrodes 1204a and 1204b and conductive layers 1206a and 1206b is removed. The insulating layer 1224 is removed by etching such as RIE using the resist as an etching mask. After the resist is removed, a Cr film and Au film are deposited on the surface of the insulating layer 1224 in this order by sputtering, thereby forming the interconnection layer 1226.

As shown in Fig. 11I, an interconnection pattern is formed on the interconnection layer 1226. More specifically, a resist is applied to the surface of the interconnection layer 1226. Exposure and development are performed, and the resist is removed from a region where no interconnection is to be formed. The interconnection layer 1226 is removed by etching such as RIE using the resist as an etching mask, thereby forming the interconnection pattern. Then, the resist is removed.

As shown in Fig. 11J, an insulating layer 1228 and conductive film 1230 are formed on the insulating layer 1224 and interconnection layer 1226. More specifically, the insulating layer 1228 as a silicon oxide film having a thickness of about 1  $\mu\text{m}$  is formed by e.g. plasma CVD. A Cr film and Au film are deposited on the surface of the insulating layer 1228 in this order by sputtering to form the conductive film 1230. The conductive film 1230 is grounded and thus functions as an anti-charge-up metal layer for the insulating layer 1228.

As shown in Fig. 11K, a resist 1232 is applied to the surface of the conductive film 1230. Exposure and development are performed, and the resist 1232 is removed from a region where an opening 200 through which an electron beam should pass. Using the resist 1232 as an etching mask, the conductive film 1230 is

removed by etching such as ion milling, and the insulating layers 1224 and 1228 are removed by etching such as RIE.

As shown in Fig. 11L, the substrate 1202 is removed by etching such as ICP-RIE using the resist 1232 as an etching mask. At this time, the opening 200 having an I shape when viewed from the upper side is formed.

As shown in Fig. 11M, the portions of the insulating layers 1208a, 1208b, 1208c, and 1208d, which are exposed to the opening 200, the insulating layer 1218, and the conductive film 1216 are removed by etching. More specifically, while leaving the resist 1232, the insulating layers 1208a, 1208b, 1208c, and 1208d as silicon oxide films on the sidewall of the opening 200 are removed by wet etching using a solution mixture of, e.g., HF and  $\text{NH}_4\text{F}$ . Simultaneously, the insulating layer 1218 is also removed by wet etching. The Cr film of the conductive film 1216 is removed by wet etching using a solution mixture of, e.g., cerium ammonium nitrate (IV), perchloric acid, and water. The Au film of the conductive film 1216 is removed by wet etching using a solution mixture of, e.g., potassium iodide, iodine, and water.

As shown in Fig. 11N, after the resist 1232 is removed, the silicon nitride film 1210b is removed by etching. More specifically, the silicon nitride film

1210b is removed by wet etching using, e.g., hot phosphoric acid to make the opening 200 through. In this embodiment, the lower surface of the substrate 1202 is exposed. However, a conductive film may be  
5 formed on the lower surface of the substrate 1202 to prevent the substrate 1202 from being charged up. In the above way, the blanking aperture array device 26 is completed by the manufacturing method shown in Figs. 11A to 11N.

10           According to the blanking aperture array device 26 according to the third embodiment, since the deflection electrodes 1204a and 1204b and conductive layers 1206a and 1206b have the same structure, the deflection electrodes 1204a and 1204b and conductive  
15 layers 1206a and 1206b can be simultaneously formed. For this reason, the number of steps in manufacturing the blanking aperture array device 26 can be decreased.  
[Fourth Embodiment]

          The fourth embodiment will be described next.  
20 The arrangement of an electron beam exposure apparatus 100, the structure of a blanking aperture array device 26, and the structure of an aperture portion 160 are the same as in the first embodiment (Figs. 1 to 3).

          Fig. 12 shows the detailed structure of the  
25 blanking aperture array device 26 according to the fourth embodiment. The blanking aperture array device 26 comprises: a substrate 2202 having a through hole

200 through which an electron beam should pass and two groove portions 2201a and 2201b formed in two side surfaces opposite to each other inside the through hole 200; two deflection electrodes 2204a and 2204b which  
5 oppose each other in the through hole 200 so as to deflect an electron beam and are at least partially buried in the two groove portions 2201a and 2201b; and insulating layers 2208a and 2208b formed between the substrate 2202 and the buried portion of the deflection  
10 electrode 2204a and between the substrate 2202 and the buried portion of the deflection electrode 2204b in the groove portions 2201a and 2201b.

The groove portions 2201a and 2201b have shapes to lock the buried portions of the deflection  
15 electrodes 2204a and 2204b in the groove portions 2201a and 2201b to prevent the deflection electrodes 2204a and 2204b from separating from the substrate 2202. More specifically, in the section almost perpendicular to the electron beam irradiation direction, i.e., the  
20 direction of thickness of the substrate 2202, preferably, the maximum width of the buried portion of the deflection electrode 2204a in the groove portion 2201a is larger than the width of the upper surface of the groove portion 2201a, and the maximum width of the  
25 buried portion of the deflection electrode 2204b in the groove portion 2201b is larger than the width of the upper surface of the groove portion 2201b. In

addition, the maximum width of each of the deflection electrodes 2204a and 2204b in the through hole 200 is preferably larger than the width of the upper surface of a corresponding one of the groove portions 2201a and 2201b. The upper surface of each of the groove portions 2201a and 2201b indicates the interface (contact surface) between the through hole 200 and each of the groove portions 2201a and 2201b.

For example, as shown in Fig. 12, the buried portions of the deflection electrodes 2204a and 2204b in the groove portions 2201a and 2201b and the groove portions 2201a and 2201b have trapezoidal columnar shapes. The deflection electrodes 2204a and 2204b are held while engaging with the groove portions 2201a and 2201b, respectively.

The groove portions 2201a and 2201b may be formed partially in the direction of thickness of the substrate 2202 or from the upper surface to the lower surface. The deflection electrodes 2204a and 2204b may be formed partially in the direction of thickness of the substrate 2202 or from the upper surface to the lower surface. The buried portions of the deflection electrodes 2204a and 2204b in the groove portions 2201a and 2201b may be formed partially in the direction of thickness of the substrate 2202 or from the upper surface to the lower surface.

The substrate 2202 is, e.g., a silicon substrate.

The insulating layers 2208a and 2208b are oxide films formed by thermally oxidizing the substrate 2202 and, for example, silicon oxide films formed by thermally oxidizing a silicon substrate. The insulating layers 2208a and 2208b may be formed only inside the groove portions 2201a and 2201b. The insulating layers 2208a and 2208b may be formed to the through hole 200 across the interfaces from the groove portions 2201a and 2201b. That is, the insulating layers 2208a and 2208b may be partially exposed to the through hole 200 from the groove portions 2201a and 2201b.

The groove portion 2201a and deflection electrode 2204a preferably have similar shapes. The groove portion 2201b and deflection electrode 2204b preferably have similar shapes. In another example, each of the groove portions 2201a and 2201b may have a widest portion between the upper surface and the bottom surface in the section almost perpendicular to the direction of thickness of the substrate 2202. Each of the groove portions 2201a and 2201b may have a curved bottom surface. The groove portions 2201a and 2201b may extend from the center of the through hole 200 to the deflection electrodes 2204a and 2204b, or temporarily become narrow and then extend. Each of the groove portions 2201a and 2201b may be branched into a plurality of parts. The plurality of parts may extend from the center of the through hole 200 to the

deflection electrodes 2204a and 2204b. More specifically, in the section almost perpendicular to the direction of thickness of the substrate 2202, the groove portions 2201a and 2201b only need to have side  
5 surfaces for which normals heading from the groove portions 2201a and 2201b to the deflection electrodes 2204a and 2204b separate from the through hole 200.

According to the blanking aperture array device 26 of the fourth embodiment, the deflection electrodes  
10 2204a and 2204b are buried in the groove portions 2201a and 2201b. For this reason, the deflection electrodes 2204a and 2204b can be prevented from peeling off from the substrate 2202.

Figs. 13A to 13N show a method of manufacturing  
15 the blanking aperture array device 26. Figs. 13A to 13N show the section of the blanking aperture array device 26 taken along a line A - A' in Fig. 12.

First, as shown in Fig. 13A, the substrate 2202 is prepared. Silicon nitride films 2210a and 2210b are  
20 formed on the upper and lower surfaces of the substrate 2202, respectively. The silicon nitride films 2210a and 2210b may be formed either simultaneously or separately. The substrate 2202 is a silicon wafer having, e.g., a diameter of 6 inches and a thickness of  
25 200  $\mu\text{m}$ . Each of the silicon nitride films 2210a and 2210b has a thickness of, e.g., 1  $\mu\text{m}$ .

Next, as shown in Fig. 13B, a resist 2212 is

applied to the upper surface of the silicon nitride film 2210a. Exposure and development are performed, and the resist 2212 is removed from regions where the deflection electrodes 2204a and 2204b are to be formed.

5 The silicon nitride film 2210a in the regions where the deflection electrodes 2204a and 2204b are to be formed is removed by etching such as reactive ion etching (RIE) using the resist 2212 as an etching mask.

As shown in Fig. 13C, the substrate 2202 at the

10 portions where the deflection electrodes 2204a and 2204b are to be formed is removed by etching such as inductively coupled plasma etching (ICP-RIE) using both or one of the resist 2212 and silicon nitride film 2210a as an etching mask, thereby forming a plurality

15 of openings 2214a and 2214b. The openings 2214a and 2214b include spaces where the groove portions 2201a and 2201b shown in Fig. 12 should be formed. Openings where the deflection electrodes 2204a and 2204b should be formed are formed in the substrate 2202 such that

20 the openings have shapes to lock the buried portions of the deflection electrodes 2204a and 2204b in the groove portions 2201a and 2201b so that the groove portions 2201a and 2201b prevent the deflection electrodes 2204a and 2204b from separating from the substrate 2202. The

25 openings 2214a and 2214b where the deflection electrodes 2204a and 2204b should be formed are formed such that the maximum width of the buried portion of

each of the deflection electrodes 2204a and 2204b in the groove portions 2201a and 2201b becomes larger than the width of the upper surface of a corresponding one of the groove portions 2201a and 2201b. The silicon  
5 nitride film 2210b serves as an etching stopper layer in etching the substrate 2202.

As shown in Fig. 13D, the resist 2212 is removed. After that, the insulating layers 2208a and 2208b are formed on the inner walls of the openings 2214a and  
10 2214b formed in the substrate 2202. The insulating layers 2208a and 2208b are formed by, e.g., thermally oxidizing the inner walls of the openings 2214a and 2214b. More specifically, of the inner walls of the openings 2214a and 2214b formed in the substrate 2202  
15 as a silicon substrate, silicon exposed surfaces except portions covered with the silicon nitride films 2210a and 2210b are selectively thermally oxidized, thereby forming the insulating layers 2208a and 2208b as silicon oxide films.

20 As shown in Fig. 13E, a conductive film 2216 is formed on the silicon nitride film 2210b. An insulating layer 2218 is formed on the conductive film 2216. More specifically, a 50-nm thick Cr film, a 20-nm thick Au film, and a 50-nm thick Cr film are  
25 formed in this order by e.g. EB deposition to form the conductive film 2216 having a multilayered structure of Cr/Au/Cr. When the multilayered structure of Cr/Au/Cr

is formed as the conductive film 2216, the adhesion between the silicon nitride film 2210b and the conductive film 2216 can be increased. If the adhesion between the silicon nitride film 2210b and the  
5 conductive film 2216 has no problem, the conductive film 2216 may be, e.g., an Au film having a single-layered structure. The insulating layer 2218 made of a silicon oxide film is formed on the conductive film 2216 by e.g. plasma chemical vapor  
10 deposition (CVD). The silicon nitride film 2210b formed in Fig. 13A is used to electrically insulate the substrate 2202 from the conductive film 2216.

As shown in Fig. 13F, the silicon nitride film 2210a and the portions of the silicon nitride film  
15 2210b, which are exposed to the openings 2214a and 2214b, are selectively removed by, e.g., RIE. At this time, without removing the insulating layers 2208a and 2208b formed on the sidewalls of the openings 2214a and 2214b, the silicon nitride film 2210b is etched until  
20 the conductive film 2216 is exposed to the openings 2214a and 2214b. In addition, the Cr film of the conductive film 2216 is etched until the Au film is exposed. In another example, without removing the insulating layers 2208a and 2208b formed on the  
25 sidewalls of the openings 2214a and 2214b, the silicon nitride film 2210a, the portions of the silicon nitride film 2210b, which are exposed to the openings 2214a and

2214b, and the Cr film of the conductive film 2216 may be removed by wet etching using hot phosphoric acid.

As shown in Fig. 13G, the deflection electrodes 2204a and 2204b are formed inside the insulating layers 2208a and 2208b, respectively, by selectively executing electrolytic plating in the openings 2214a and 2214b by using the Au film of the conductive film 2216 as a plating electrode (seed layer). The deflection electrodes 2204a and 2204b are made of, e.g., Cu.

After the deflection electrodes 2204a and 2204b are formed, an unnecessary conductive material is removed by, e.g., chemical mechanical polishing (CMP). In another example, after Cr films are formed on the surfaces of the insulating layers 2208a and 2208b exposed to the openings 2214a and 2214b by sputtering, the deflection electrodes 2204a and 2204b may be formed inside the Cr films in the openings 2214a and 2214b. With this structure, the adhesion between the deflection electrodes 2204a and 2204b and the insulating layers 2208a and 2208b can be increased.

As shown in Fig. 13H, an insulating layer 2224 and interconnection layer 2226 are formed on the substrate 2202. More specifically, the insulating layer 2224 as a silicon oxide film having a thickness of about 1  $\mu\text{m}$  is formed by e.g. plasma CVD. A resist is applied to the surface of the insulating layer 2224. Exposure and development are performed, and the resist

above the deflection electrodes 2204a and 2204b is removed. The insulating layer 2224 is removed by etching such as RIE using the resist as an etching mask. After the resist is removed, a Cr film and Au  
5 film are deposited on the surface of the insulating layer 2224 in this order by sputtering, thereby forming the interconnection layer 2226 electrically connected to the deflection electrodes 2204a and 2204b.

As shown in Fig. 13I, an interconnection pattern  
10 is formed on the interconnection layer 2226. More specifically, a resist is applied to the surface of the interconnection layer 2226. Exposure and development are performed, and the resist is removed from a region where no interconnection is to be formed. The  
15 interconnection layer 2226 is removed by etching such as RIE using the resist as an etching mask, thereby forming the interconnection pattern. Then, the resist is removed.

As shown in Fig. 13J, an insulating layer 2228  
20 and conductive film 2230 are formed on the insulating layer 2224 and interconnection layer 2226. More specifically, the insulating layer 2228 as a silicon oxide film having a thickness of about 1  $\mu\text{m}$  is formed by e.g. plasma CVD. A Cr film and Au film are  
25 deposited on the surface of the insulating layer 2228 in this order by sputtering to form the conductive film 2230. The conductive film 2230 is grounded and thus

functions as an anti-charge-up metal layer for the insulating layer 2228.

As shown in Fig. 13K, a resist 2232 is applied to the surface of the conductive film 2230. Exposure and  
5 development are performed, and the resist 2232 is removed from a region where the through hole 200 through which an electron beam should pass is to be formed. Using the resist 2232 as an etching mask, the conductive film 2230 is removed by etching such as ion  
10 milling, and the insulating layers 2224 and 2228 are removed by etching such as RIE.

As shown in Fig. 13L, the substrate 2202 is removed by etching such as ICP-RIE using the resist 2232 as an etching mask, thereby forming the through  
15 hole 200 through which the electron beam should pass in the substrate 2202.

As shown in Fig. 13M, parts of the insulating layers 2208a and 2208b, the insulating layer 2218, and the conductive film 2216 are removed by etching. More  
20 specifically, while leaving the insulating layers 2208a and 2208b in the groove portions 2201a and 2201b, the insulating layers 2208a and 2208b on the sidewall of the through hole 200 are removed by wet etching using a solution mixture of, e.g., HF and  $\text{NH}_4\text{F}$ . Simultaneously,  
25 the insulating layer 2218 is also removed by wet etching. The Cr film of the conductive film 2216 is removed by wet etching using a solution mixture of,

e.g., cerium ammonium nitrate (IV), perchloric acid, and water. The Au film of the conductive film 2216 is removed by wet etching using a solution mixture of, e.g., potassium iodide, iodine, and water.

5           As shown in Fig. 13N, after the resist 2232 is removed, the silicon nitride film 2210b is removed by etching. More specifically, the silicon nitride film 2210b is removed by wet etching using, e.g., hot phosphoric acid to make the through hole 200 through.

10       In this embodiment, the lower surface of the substrate 2202 is exposed. However, a conductive film may be formed on the lower surface of the substrate 2202 to prevent the substrate 2202 from being charged up. In the above way, the blanking aperture array device 26 is

15       completed by the manufacturing method shown in Figs. 13A to 13N.

          According to the blanking aperture array device 26 of the fourth embodiment, the deflection electrodes 2204a and 2204b are buried in the groove portions 2201a

20       and 2201b. Even when the deflection electrodes 2204a and 2204b are formed by plating inside the insulating layers 2208a and 2208b by using a material having a relatively large residual stress after plating growth, the peeling resistance of the deflection electrodes

25       2204a and 2204b and insulating layers 2208a and 2208b can be increased. Hence, the reliability of electron beam deflection by the blanking aperture array device

26 can be increased. In addition, the service life of the blanking aperture array device 26 can be prolonged.

The present invention has been described using the embodiments. However, the technical scope of the invention is not limited to the above embodiments, and various changes and modifications can be made in the above embodiments. The changes and modifications can also be incorporated in the technical scope of the invention, as can be seen from the appended claims.

In addition, those skilled in the art can readily understand that the arrangements of the embodiments can appropriately be combined by, e.g., using the deflection electrodes 206a and 206b of the first embodiment (Fig. 5) as the deflection electrodes of the second to fourth embodiments.

As is apparent from the above description, according to the present invention, there can be provided a deflector which accurately deflects a charged particle beam and has a long service life, a method of manufacturing the deflector, and a charged particle beam exposure apparatus having the deflector.

As many apparently widely different embodiments of the present invention can be made without departing from the spirit and scope thereof, it is to be understood that the invention is not limited to the specific embodiments thereof except as defined in the claims.